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Canadian Science Advisory Secretariat
Science Advisory Report 2014/003

STOCK ASSESSMENT AND MANAGEMENT ADVICE FOR BRITISH COLUMBIA PACIFIC HERRING: 2013 STATUS AND 2014 FORECAST

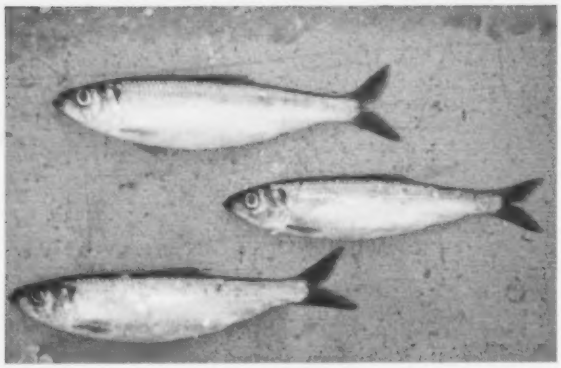

Photo: K. Daniel, DFO

Figure 1. B.C. Pacific Herring major stock areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), west coast of Vancouver Island (WCVI), and minor stock areas: Area 2W and Area 27.

Context:

Pacific Herring (Clupea pallasi) is a pelagic species inhabiting inshore and offshore waters of the North Pacific. In the eastern Pacific, herring distribution ranges from California to the Beaufort Sea. Herring annually migrate between feeding and spawning areas. Fish mature and recruit to the spawning stock primarily between ages 2 and 5. In British Columbia (BC) herring predominantly recruit at age 3. BC herring stocks are managed based on five major and two minor stock areas. The five major BC herring stocks are Haida Gwaii (Area 2E), Prince Rupert District, Central Coast, Strait of Georgia, and West Coast of Vancouver Island, while the two minor herring stocks are Area 2W and Area 27 (Figure 1). Catch and survey information is collected independently for each of these seven areas and science advice is provided on the same scale.

Oceans and Fisheries Management Branch annually requests science advice regarding the status of herring stocks in BC and harvest options. Advice was also requested on recruitment forecasting methods and compliance with DFO's Fisheries Decision-Making Framework Incorporating the Precautionary Approach. Annual stock assessments and forecasts of abundance are carried out using a Bayesian statistical catch-at-age model. This report summarizes the results of the 2013 annual assessment and recommendations on 2014 harvest options and it provides advice on recruitment forecasting methods.

This Science Advisory Report is from the September 4-6, 2013 Regional Peer Review meeting on Stock Assessment and Management Advice for BC Pacific Herring: 2013 Status and 2014 Forecast. Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule.

January 2014

Canada

SUMMARY

- Commercial fishing for British Columbia (BC) Pacific Herring is managed as five major stock management areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), and West Coast of Vancouver Island (WCVI), and two minor herring stock management areas: Haida Gwaii Area 2W, and WCVI Area 27 (Figure 1).
- Recruitment forecasting methodologies were reviewed to assess how uncertainty is represented in the forecasts, and to assess compliance with DFO's Fisheries Decision-making Framework Incorporating the Precautionary Approach.
- The previous forecasting approach of using trawl survey data to forecast recruitment in two stocks (WCVI, SOG) and the categorization of model-reconstructed recruits (as poor/ average/good categories) applied to all stocks could produce an incorrect perception of forecast stock size and uncertainty.
- It was concluded that the previous approach is not scientifically defensible and that it does not capture the uncertainty in recruitment forecasts and subsequent risks to BC Pacific Herring stocks.
- Consequently, it is recommended that the assessment model be used to estimate the probability of breaching thresholds or achieving desirable outcomes for BC Pacific Herring stocks and fisheries.
- The 2013 spawning biomass and forecast of the 2014 spawning biomass were assessed using an integrated statistical catch-at-age model ("the assessment model"). Advice for each Pacific Herring stock is presented in probabilistic decision tables showing predicted status in 2014 given a range of constant catches relative to target harvest rates and performance metrics relating directly to the existing herring harvest control rule.
- The assessment results and advice are summarized by management area below. All herring biomass results are reported in metric tonnes (t). *SB* denotes spawning biomass. Stock status is measured relative to equilibrium unfished spawning biomass (SB_0).
- Recommendations for future work include evaluating current and proposed alternative Pacific Herring management approaches, including the use of alternative reference levels, via simulation testing. Additional recommendations for future work include evaluating the drivers of recruitment forecasts produced by the assessment model, incorporating sources of fishing mortality not currently captured (e.g., spawn-on-kelp), and the development of biologically-based limit reference points.
- All quantities in the summaries below are reported as the 5 – 95% credible interval with the median value in parentheses – the quantity has a 90% probability of lying in the credible interval.

Haida Gwaii (HG)

- All herring spawning from Cumshewa Inlet in the north to Louscoone Inlet in the south are assumed to be part of the Haida Gwaii stock.
- No commercial herring fishery occurred in this area from 2005 through 2013.
- The estimated spawning biomass in 2013 (SB_{2013}) is 14,357 – 54,537 t (median: 28,294 t). SB_{2013} is estimated to be 0.42 – 1.49 (median: 0.80) of SB_0.
- Median spawning biomass has increased since 2008, in part due to increases in the spawn index from 2011 to 2013, above average recruitment in 2010 to 2013, and possibly decreases in natural mortality.
- The projected spawning stock biomass in 2014, assuming no catch, is 12,270 – 58,540 t (median: 26,260 t), consisting of 9 – 74% (median: 36%) age-3 fish and 19 – 83% (53%)

age-4 and older fish. There is high uncertainty in the estimates of the number of age-3 fish in 2014.

Prince Rupert District (PRD)

- All herring spawning in Statistical Areas 3 to 5 are assumed to belong to the Prince Rupert District stock.
- Commercial seine roe and gillnet roe fisheries caught 743 t and 1,284 t, respectively, in 2013. Commercial spawn on kelp operations also occurred (five licenses).
- SB_{2013} is estimated to be 16,762 – 60,283 t (median: 32,568 t) and is estimated to be 0.25 - 0.90 (median: 0.49) of SB_0.
- Median spawning biomass has increased since 2012 as a result of increases in the spawning index (since 2010), above average recruitment in 2013 and possibly decreases in natural mortality.
- The projected spawning stock biomass in 2014, assuming no catch, is 19,750 – 109,500 t (median: 44,840 t), consisting of 11 – 82% (median: 49%) age-3 fish and 15 – 82% (median: 45%) age-4 and older fish. There is high uncertainty in the estimates of the number of age-3 fish in 2014. The estimated recruitment of age-2 fish in 2013 was similar to historical values from the early 1960s and the highest estimate since this period.

Central Coast (CC)

- All herring spawning in Kitasu Bay (a portion of Statistical Area 6), in Statistical Area 7, and in part of Statistical Area 8 (Kwakshua Channel and Fitzhugh Sound) are assumed to be part of the Central Coast stock.
- No commercial herring fishery occurred in this area from 2008 through 2013.
- SB_{2013} is estimated to be 17,844 – 48,974 t (median: 29,597 t) and is estimated to be 0.29 - 0.78 (median: 0.48) of SB_0.
- Median spawning biomass increased from 2011 through 2013 in part due to above average recruitment in 2008, 2010, and 2012, a high spawn index in 2013 (although this was preceded by seven years with low index values), and apparent decreases in natural mortality.
- The projected spawning stock biomass in 2014, assuming no catch, is 13,230 – 41,210 t (median: 23,370 t), consisting of 13 – 29% (median: 20%) age-3 fish and 53 – 78% (median: 68%) age-4 and older fish.

Strait of Georgia (SOG)

- All herring spawning in Statistical Areas 14 to 19, 28 and 29 (excluding Section 293), and part of 13 (Herring Sections 132 and 135, Deepwater Bay area south) are assumed to belong to the Strait of Georgia herring stock.
- 2013 catch in the winter seine fishery (food and bait, special use) was 4,530 t, in the seine roe fishery was 6,099 t, and in the gillnet roe fishery was 5,937 t.
- SB_{2013} is estimated to be 83,196 – 220,752 t (median: 136,258 t) and is estimated to be 0.62 – 1.48 (median: 0.97) of SB_0.
- Median spawning biomass has increased since 2010 due in part to above average recruitment in 2010 and 2011 and apparent decreases in natural mortality.
- The projected spawning stock biomass in 2014, assuming no catch, is 73,260 – 206,000 t (median: 123,300 t), consisting of 27 – 43% (median: 35%) age-3 fish and 42 – 60% (median: 52%) age-4 and older fish.

West Coast Vancouver Island (WCVI)

- All herring spawning in Statistical Areas 23 to 25 are assumed to belong to the west coast of Vancouver Island herring stock.
- The WCVI stock has been closed to commercial fisheries from 2006 to 2011 and in 2013. A commercial harvest option was available in 2012 but was not pursued.
- SB_{2013} is estimated to be 12,782 – 38,799 t (median: 22,464 t) and is estimated to be 0.23 – 0.66 (median: 0.40) of SB_0.
- Median spawning biomass has increased since 2008 from historically low levels due in part to above average recruitment in 2010 and apparent decreases in natural mortality.
- The projected spawning stock biomass in 2014, assuming no catch, is 11,880 – 39,360 t (median: 21,770 t), consisting of 19 – 38% (median: 28%) age-3 fish and 37 – 64% (median: 52%) age-4 and older fish.

Area 2W

- All herring spawning in Statistical Area 2W (except Herring Section 006) are assumed to belong to this Haida Gwaii minor stock.
- A commercial spawn-on-kelp fishery occurred in this area in 2013 (two licenses).
- SB_{2013} is estimated to be 1,557 – 9,171 t (median: 3,938 t) and is estimated to be 0.45 – 2.23 (median: 1.10) of SB_0.
- Median spawning biomass has declined since 2011 in part due to a decrease in the spawn index since 2010 and possibly increases in natural mortality. Above average recruitment occurred in 2013.
- The projected spawning stock biomass in 2014, assuming no catch, is 1,520 – 11,761 t (median: 4,427 t), consisting of 8 – 56% (median: 33%) age-3 fish and 41 – 89% (median: 64%) age-4 and older fish. There is high uncertainty in the estimates of the number of age-3 fish in 2014.

Area 27

- All herring spawning in Statistical Area 27 are assumed to belong to this West Coast of Vancouver Island minor stock.
- A commercial spawn-on-kelp fishery occurred in this area in 2013 (two licenses).
- SB_{2013} is estimated to be 645 – 2,239 t (median: 1,185 t) and is estimated to be 0.31 – 0.98 (median: 0.55) of SB_0.
- Median spawning biomass has remained relatively constant over the past decade while natural mortality may have decreased over the same period. Below average recruitment occurred in 2011-2013.
- The projected spawning stock biomass in 2014, assuming no catch, is 533 – 2,090 t (median: 1,020 t), consisting of 8 – 28% (median: 16%) age-3 fish and 52 – 84% (median: 71%) age-4 and older fish.

INTRODUCTION

Pacific Herring (*Clupea pallasi*) is a pelagic species migrating between inshore spawning and offshore feeding areas of the North Pacific Ocean. Herring distribution in the eastern Pacific Ocean ranges from California to the Beaufort Sea. Pacific Herring mature and recruit to the spawning stock predominantly at age-3 within British Columbia (BC), but age-at-recruitment tends to increase with latitude within this range.

Pacific Herring in British Columbia are divided into five major and two minor stocks (Figure 1) for evaluation and management. This stock structure is supported in part by the results of multi-year tagging and genetic studies (Hourston 1982, Beacham et al. 2008, Flostrand et al. 2009). The major stocks are: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG) and West Coast of Vancouver Island (WCVI). The two minor herring stocks are Area 2W (on the west coast of Haida Gwaii) and Area 27 (on the west coast of Vancouver Island, centered on Quatsino Sound).

Pacific Herring in BC have been harvested for many years to provide a variety of food products. First Nations have traditionally harvested whole herring and herring spawn-on-kelp for food, social and ceremonial purposes. Pacific Herring were commercially harvested and processed (reduced) into relatively low-value products such as fishmeal and oil from the early 1930s through the late 1960s. Commercial catches increased dramatically in the early 1960s, but were unsustainable and by 1965, most of the older fish had been removed from the spawning population by overfishing and a combination of sequential weak year-classes attributed to unfavourable environmental conditions and low spawning biomass. The commercial fishery collapsed and was closed by the federal government in 1967. During the closure period limited fishing activity occurred at low levels from 1967-1971 (Hourston 1980). Growing interest in harvesting roe herring for export to Japan resulted in a small experimental roe harvest, beginning in 1971. The roe fishery expanded rapidly until 1983, when a fixed harvest rate was introduced to regulate catch. A series of above average year-classes in the early 1970s led to rapid rebuilding of Pacific stocks and the re-opening of areas for commercial fishing.

At present, the Pacific Herring fisheries in BC consist of commercial fishing opportunities for food and bait herring, spawn-on-kelp products, and roe herring, First Nations food, social, and ceremonial fisheries (FSC), and recreational opportunities. Combined commercial removals for 2007 to 2013 from the roe and food and bait, and special use fisheries operating in the five major and two minor BC Herring stock assessment areas are shown in Table 1.

Table 1. Combined commercial removals (tonnes) from roe, and food and bait and special use fisheries operating in the BC herring stock assessment areas from 2007 to 2013. Spawn-on-kelp fishery removals are not included in this table.

Stock Area	2007	2008	2009	2010	2011	2012	2013
Haida Gwaii	0	0	0	0	0	0	0
Prince Rupert District	970	1,662	2,000	1,484	2,147	1,383	2,027
Central Coast	398	0	0	0	0	0	0
Strait of Georgia	9,822	9,934	10,170	8,324	5,128	11,339	16,566
West Coast Vancouver Island	0	0	0	0	0	0	0
Area 2W	0	0	0	0	0	0	0
Area 27	0	0	0	0	0	0	0

Management of BC Pacific Herring stocks has historically been directed by a Management Framework based on science advice initially approved in 1986, and further refined in 1996, for 5 major and two minor stock areas in BC. The framework established a commercial fishery cut-off at 25% of the estimated unfished spawning biomass (SB_0) for each major stock assessment area. A 20% harvest rate was applied to the forecasted pre-fishery stock biomass that exceeded the cut-off. The minor herring stocks (Areas 2W and 27) were not subject to a commercial fishery cut-off; instead, a 10% harvest rate was applied.

DFO's Oceans and Fisheries Management Branch requested advice on present trends in herring biomass, depletion, and recruitment for each major and minor stock in BC, an assessment of the current status of Pacific Herring for each of the five major and two minor stocks relative to estimates of unfished equilibrium spawning biomass (SB_0) and projections of the consequences of different total allowable catch levels against probabilistic harvest and spawning biomass metrics to account for uncertainty in the advice. In addition, an evaluation of external recruitment forecasting methodologies for BC Herring stocks was conducted to assess the validity of sampling and analytical approaches and for consistency with the DFO policy "A fishery decision-making framework incorporating the Precautionary Approach" (DFO 2009) requirement to consider uncertainty in decision making.

ASSESSMENT

Review of External Recruitment Forecasting Methods

Historically, recruitment forecasts corresponding to Poor, Average, and Good (PAG) levels of the expected numbers of age-3 fish were derived from estimates of age-3 fish obtained from the stock reconstruction produced by the assessment model. The PAG categories were formed by the 33rd and 66th percentiles of the model estimates (Poor <= 33rd, Average 33rd-66th, Good > 66th percentiles. Forecasting methodologies for the major stocks used one of two methods to replace the model forecast of the numbers of age-3 fish with an alternative value. For the HG, CC, and PRD stocks the model forecast of the numbers of age-3 fish were replaced with an alternative value determined by inspection of recently assigned expected numbers of age-3 fish to the Poor, Average and Good categories, and spawning stock status relative to 0.25 SB_0. Forecasts for the SOG and WCVI stocks used the same procedure for defining the Poor, Average and Good categories that was applied to the HG, PRD and CC stocks, but used an estimate of the proportion at age-2+ fish derived from a summer mid-water trawl survey off the West Coast of Vancouver Island to select the recruitment category. Recruitment forecasting methodologies were reviewed to assess how uncertainty is represented in the forecasts, and to assess compliance with DFO's Fisheries Decision-making Framework Incorporating the Precautionary Approach. It was concluded that historical and recent recruitment forecasting methods were not consistent with the policy requirement of quantifying uncertainty, that uncertainty in PAG forecasts may be under-represented compared to the full uncertainty quantified by the catch-age model, and that uncertainty is not propagated through to decision tables.

Stock Assessment Modeling for 2013

The integrated statistical catch-at-age model (ISCAM) was reviewed and approved for use in 2011 (Martell et al., 2012) and has since been used for the provision of science advice in 2011, 2012, and 2013. This combined-sex, catch-at-age model was applied independently to each stock area and tuned to fishery-independent spawn index data, annual estimates of commercial catch since 1951, and age composition data from the commercial fishery and from the test fishery charter program. The key results from stock assessments of Pacific Herring in five major and two minor stock areas are summarized as stock reconstructions, status of spawning stock in 2013, and projected spawning biomass in 2014.

The model estimates stock-recruitment parameters (recruitment is modelled as age-2 fish while recruitment to the spawning biomass occurs at age-3), time-varying natural mortality, catchability coefficients for the survey time series, and selectivity parameters for the commercial fishery and those survey series for which age data are available. One-year projections for 2014 are performed for each major and minor stock area over a range of constant catches to estimate

probabilities that spawning biomass and harvest rate metrics are below and above control points, respectively, as specified in the herring harvest control rule (HCR). All calculations are made using the Bayesian Markov Chain Monte Carlo (MCMC) method to quantify the uncertainty associated with parameter estimation. This approach yields 5,000 MCMC samples from posterior distributions. Estimates of various quantities are calculated from these samples, and are presented as the 5-95% credible interval with median values in parentheses. Calculated probabilities are based on joint posterior distributions. Uncertainty associated with truncated catch data (1972 – present) and an adjustment in the spawn index (2003-2013) to account for lead-line changes were explored through sensitivity runs.

Advice to managers on estimated (current) spawning biomass, SB_{2013}, estimated unfished equilibrium spawning biomass (SB_0), estimated ratio SB_{2013}/SB_0, and trends in age-2 recruitment and instantaneous natural mortality are presented in Figures 2-9. Tables 2 and 3 give estimates of spawning biomass in recent years (SB_t), SB_0, 0.25 SB_0, and the ratio SB_{2013}/SB_0. Description and interpretation by stock area is summarized in the Summary section above (pgs. 2-4). Summaries include reference to years of above (or below) average recruitment, referring to years where recruitment was high or low relative to predictions from the Beverton-Holt stock recruitment relationship.

Table 2. Median estimates (with 5-95% credible interval) of spawning biomass (SBt) for BC herring stocks, 2007-2013.

Stock Area	2007	2008	2009	2010	2011	2012	2013
HG	10,700 (7,066-16,167)	10,151 (6,758-15,123)	11,609 (7,625-17,667)	11,757 (7,665-17,972)	12,681 (8,126-19,884)	17,990 (10,607-29,697)	28,294 (14,357-54,537)
PRD	20,998 (14,627-31,082)	20,886 (14,851-30,444)	19,980 (14,162-29,373)	21,292 (14,937-31,800)	22,799 (15,246-35,138)	22,301 (13,610-36,189)	32,568 (16,762-60,283)
CC	13,368 (9,003-19,796)	12,777 (8,736-18,602)	16,218 (11,208-23,642)	16,106 (11,170-23,182)	16,003 (11,035-23,272)	19,177 (12,971-28,569)	29,597 (17,844-48,974)
SOG	111,277 (79,269-157,119)	74,103 (52,894-103,887)	80,129 (56,569-112,736)	72,887 (50,338-104,331)	108,906 (76,283-157,742)	125,030 (86,124-182,816)	136,258 (83,196-220,752)
WCVI	8,715 (5,767-13,477)	7,779 (5,153-12,005)	8,521 (5,611-13,302)	11,599 (7,582-18,017)	16,682 (11,005-25,785)	19,335 (12,371-30,591)	22,464 (12,782-38,799)
Area 2W	1,734 (1,001-2,880)	2,046 (1,196-3,391)	3,016 (1,730-4,988)	3,692 (2,125-6,190)	3,994 (2,179-7,080)	3,910 (1,944-7,681)	3,938 (1,557-9,171)
Area 27	1,727 (1,158-2,576)	1,531 (1,026-2,292)	1,621 (1,074-2,482)	1,427 (937-2,191)	1,301 (846-2,030)	1,134 (709-1,882)	1,185 (645-2,239)

Table 3. Median estimates (with 5-95% credible interval) of 2013 spawning biomass (SB_{2013}), unfished spawning biomass (SB_0), 0.25 SB_0, and the ratio SB_{2013}/SB_0 for all BC herring stocks.

Stock	Spawning biomass (SB_{2013})			Unfished equilibrium spawning biomass (SB_0)			0.25*SB_0			Median ratio of spawning biomass to unfished equilibrium spawning biomass (SB_{2013}/SB_0)		
	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
HG	14,357	28,294	54,537	26,336	34,962	48,390	6,584	8,741	12,098	0.42	0.80	1.49
PRD	16,762	32,568	60,283	50,000	64,928	95,558	12,500	16,232	23,889	0.25	0.49	0.90
CC	17,844	29,597	48,974	49,194	61,618	81,250	12,299	15,405	20,313	0.29	0.48	0.78
SOG	83,196	136,258	220,752	113,653	139,511	180,183	28,413	34,878	45,046	0.62	0.97	1.48
WCVI	12,782	22,464	38,799	45,591	56,885	72,047	11,398	14,221	18,012	0.23	0.40	0.66
Area 2W	1,557	3,938	9,171	2,070	3,565	6,907	518	891	1,727	0.45	1.10	2.33
Area 27	645	1,185	2,239	1,457	2,123	3,169	364	531	792	0.31	0.55	0.98

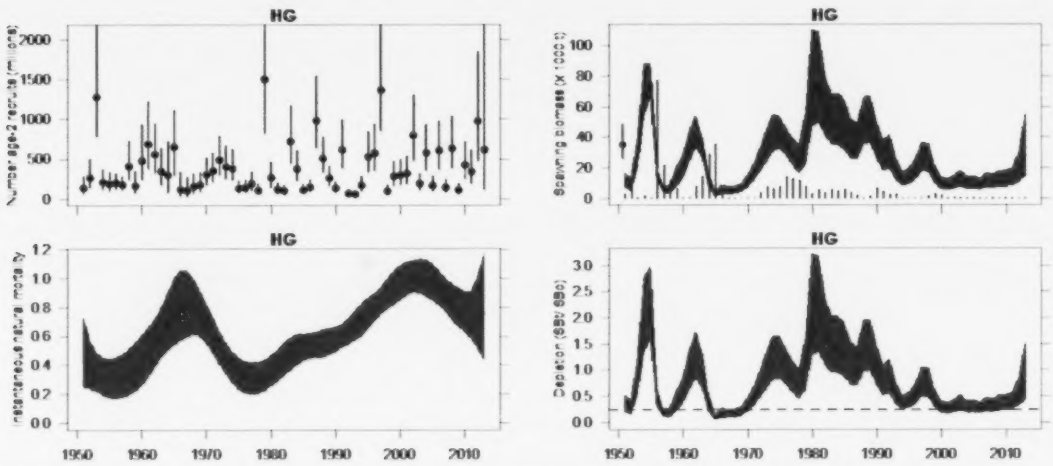

Figure 2. Summary of the dynamics of the HG stock from 1951 to 2013, where solid circles with vertical lines, and solid lines with surrounding pink envelopes, represent medians and 5-95% credible intervals. Upper left panel shows the reconstruction of number of age-2 recruits. (millions).; Lower left panel shows the reconstruction of instantaneous natural mortality; Upper right panel shows the reconstruction of spawning biomass (SB_t) for each year t, with unfished values shown at far left (solid circle and vertical line). Time series of vertical lines denote commercial catch (excluding commercial SOK); Lower right panel shows the median ratio (SB_t/SB_0) of spawning biomass to unfished equilibrium spawning biomass. Dashed horizontal line denotes 0.25 SB_0.

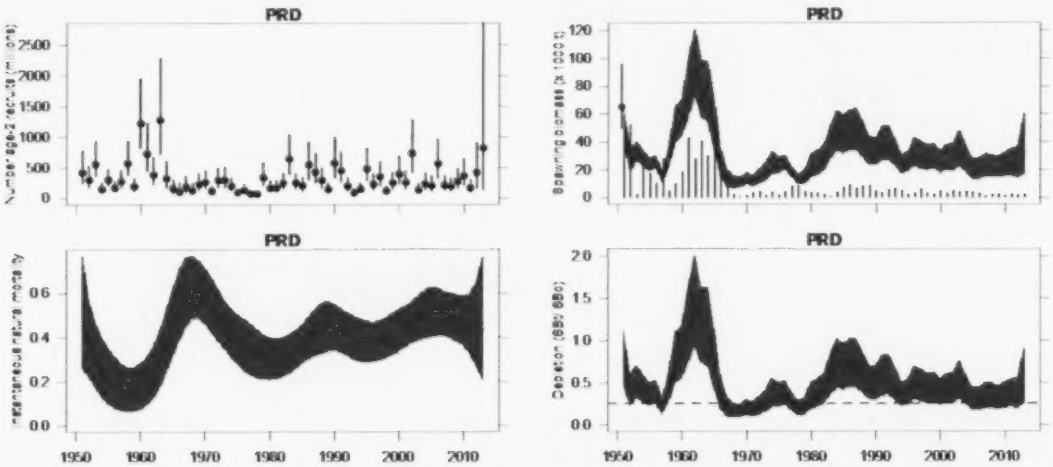

Figure 3. Summary of the dynamics of the PRD stock from 1951 to 2013. See Figure 2 for detailed description.

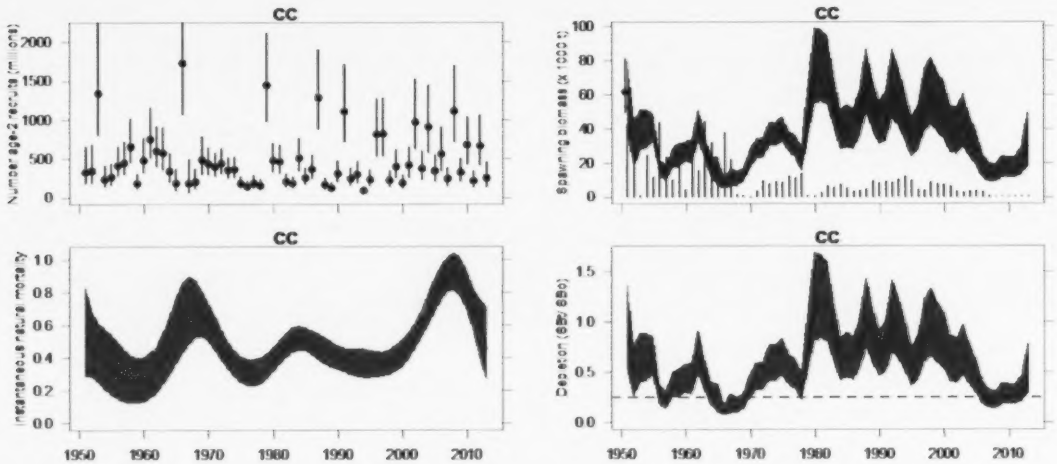

Figure 4. Summary of the dynamics of the CC stock from 1951 to 2013. See Figure 2 for detailed description.

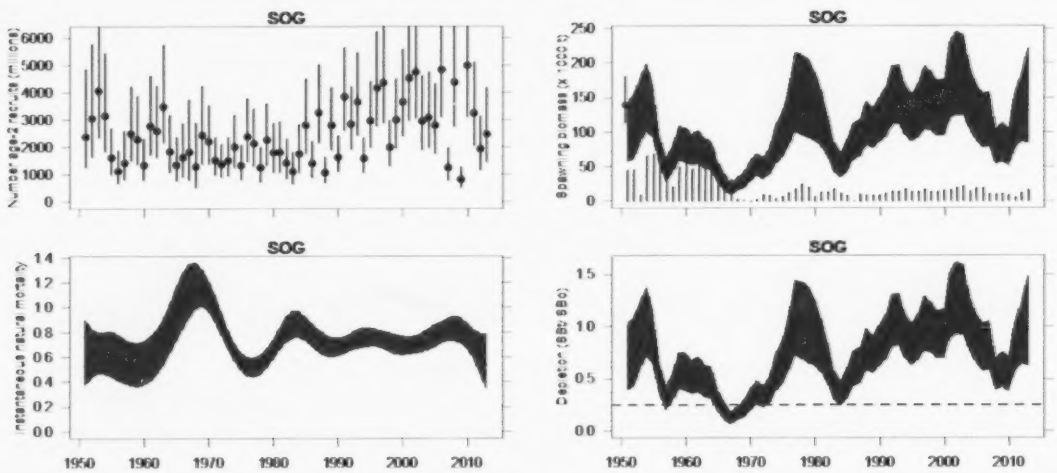

Figure 5. Summary of the dynamics of the SOG stock from 1951 to 2013. See Figure 2 for detailed description.

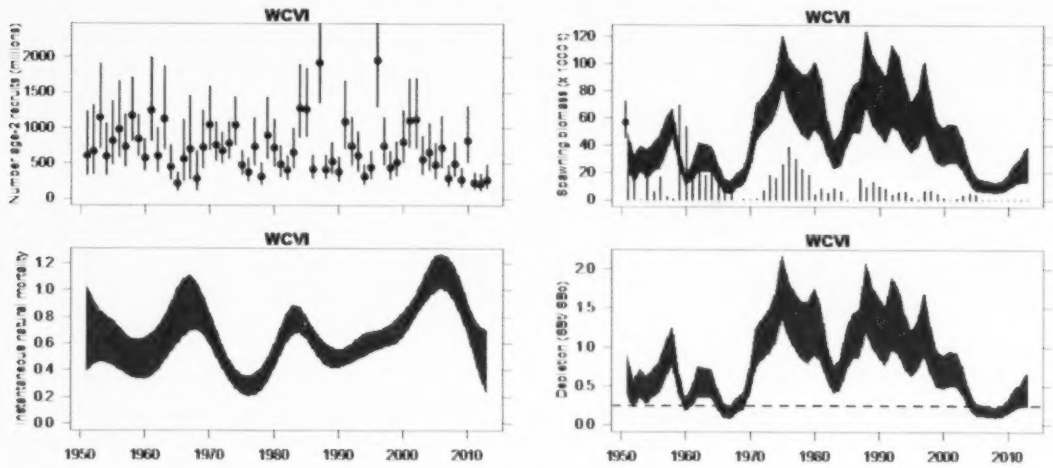

Figure 6. Summary of the dynamics of the WCVI stock from 1951 to 2013. See Figure 2 for detailed description.

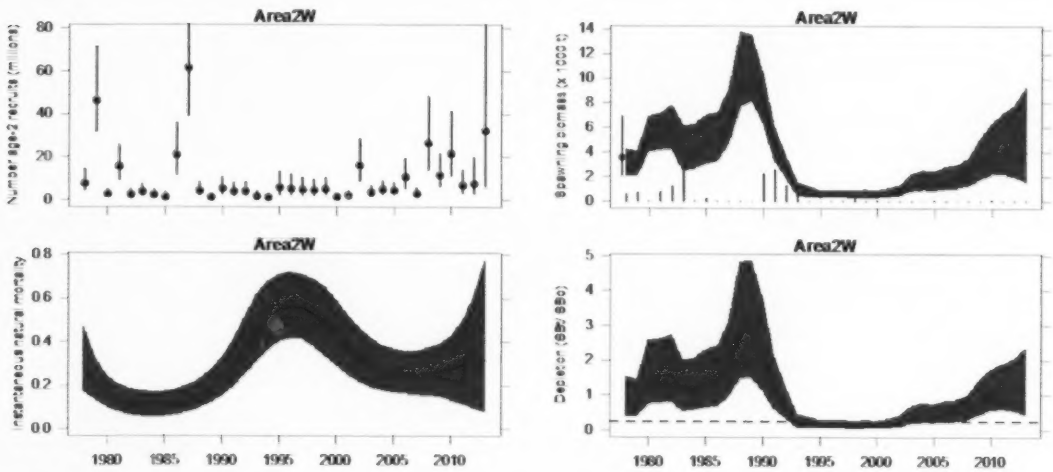

Figure 7. Summary of the dynamics of the Area 2W stock from 1951 to 2013. See Figure 2 for detailed description.

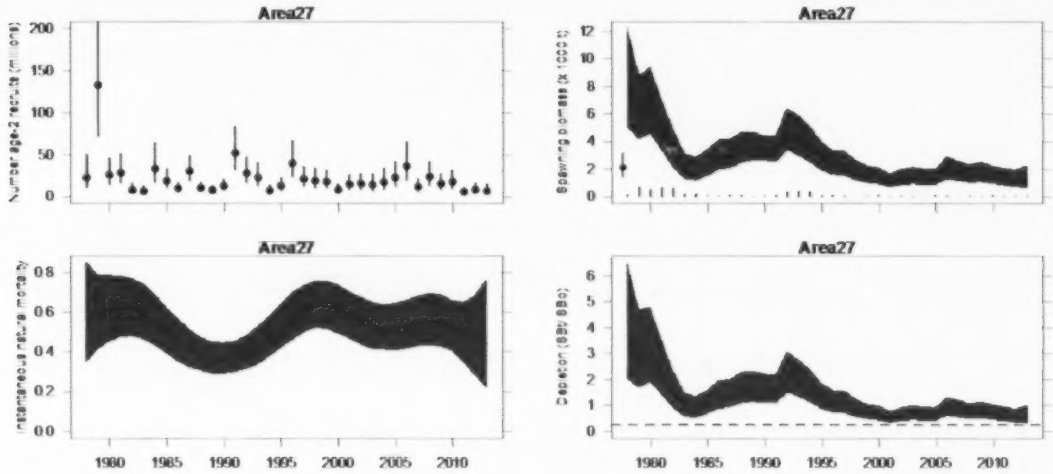

Figure 8. Summary of the dynamics of the Area 27 stock from 1951 to 2013. See Figure 2 for detailed description.

Projection Results and Decision Tables

Projected spawning biomasses assuming zero catch in 2014 and the relative contribution of fish of age-3 and of ages 4-10 are presented in Table 4. Advice to managers for 2014 for the major stock areas is presented as a set of decision tables that provide probabilities of the projected spawning biomass in 2014 (SB_{2014}) falling below the 0.25 SB_0 level and of the realized harvest rate exceeding the 20% target rate for a range of constant catch levels (Table 5). Decision tables for minor stock areas provide probabilities of the realized harvest rate exceeding the 10% target rate for a range of constant catch levels (Table 5).

Projections of spawning biomass in 2014 (SB_{2014}) were made over a range of yield options from 0 t to a maximum well above recent historical catches in increments that vary depending on the productivity of the stock. The decision table for each major and minor herring stock includes a catch option corresponding to a 20% and 10% harvest rate, respectively.

Decision tables (Table 5) include the probabilities that SB_{2014} will be below the 0.25 SB_0 level and that the realized harvest rate will be greater than 20% in 2014 for each catch level. Note that catches are held constant, so there is no reduction of the catch in the projections if SB_{2014} is less than 0.25 SB_0.

As an example of how to read the tables for the five major stock areas (HG, PRD, CC, SOG, WCVI): given a catch of 4,000 t from the Haida Gwaii stock, the estimated probability that the realized harvest rate (U) exceeds the 20% target rate is 23%, the ratio of SB_{2014}/0.25 SB_0 value is 2.73 and the probability that SB_{2014} < 0.25 SB_0 is estimated to be 3%.

The decision tables for the minor stocks (Area 2W, Area 27) do not include biomass performance metrics because biomass metrics were not historically used. For example, given a catch of 400 t in Area 2W, the estimated harvest rate in 2014 (Med U_{2014}) is 9% and the probability that U_{2014} > 10% is estimated to be 43%.

Table 4. Estimates of projected spawning biomass in 2014 given zero catch, and predicted proportions of fish of age-3 and of ages 4-10 for all BC herring stocks.

Stock	Projected proportion age-3 fish in 2014			Projected proportion ages 4-10 fish in 2014			Projected spawning biomass (SB_{2014}) given zero catch		
	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
HG	0.09	0.36	0.74	0.19	0.53	0.83	12,270	26,260	58,540
PRD	0.11	0.49	0.82	0.15	0.45	0.82	19,750	44,840	109,500
CC	0.13	0.20	0.29	0.53	0.68	0.78	13,230	23,370	41,210
SOG	0.27	0.35	0.43	0.42	0.52	0.60	73,260	123,300	206,000
WCVI	0.19	0.28	0.38	0.37	0.52	0.64	11,880	21,770	39,360
Area 2W	0.08	0.33	0.56	0.41	0.64	0.89	1,520	4,427	11,761
Area 27	0.08	0.16	0.28	0.52	0.71	0.84	533	1,020	2,090

Table 5. Decision tables concerning the harvest and biomass metrics drawn from the herring harvest control rule for projected spawning biomass in 2014 given a range of constant annual catch strategies (in tonnes) for major stock areas HG, PRD, CC, SOG, and WCVI. Decision tables for minor stock areas (Area 2W, Area 27) show harvest metrics only because biomass metrics were not historically used. Values are the probabilities, under each annual catch strategy, of the spawning biomass in 2014 (SB_{2014}) being lower than 0.25 SB_0, and of the harvest rate being greater than 20%. The probabilities are the proportion of the MCMC samples for which the given criteria hold.

	Biomass metrics		Harvest metrics	
TAC (metric tonnes)	Prob (below 0.25 SB_0 in 2014) P(SB2014 < 0.25 SB0)	Median ratio of forecast biomass to 0.25 SB_0 Med (SB2014 / 0.25 SB0)	Prob (removal rate > target HR) P(U'2014 > 20%)	Median removal rate Med (U'2014)
Haida Gwaii				
0	0.01	3.02	0	0
2,000	0.01	2.88	0.01	0.07
3,000	0.02	2.81	0.08	0.11
4,000	0.03	2.73	0.23	0.14
5,000	0.03	2.66	0.39	0.18
5,750	0.04	2.61	0.5	0.2
6,000	0.04	2.59	0.55	0.21
7,000	0.05	2.52	0.66	0.24
8,000	0.07	2.45	0.75	0.27
9,000	0.08	2.38	0.82	0.3
Prince Rupert District				
0	0.02	2.71	0	0
2,500	0.03	2.6	0	0.06
5,000	0.05	2.48	0.1	0.11
7,500	0.07	2.37	0.33	0.16
9,500	0.09	2.28	0.5	0.2
10,000	0.1	2.26	0.54	0.21
12,500	0.12	2.15	0.7	0.26
15,000	0.15	2.04	0.81	0.31
17,500	0.18	1.94	0.87	0.35
Central Coast				
0	0.11	1.51	0	0
1,000	0.13	1.46	0	0.04
2,000	0.16	1.42	0.01	0.08
3,000	0.19	1.38	0.07	0.12
4,000	0.22	1.33	0.25	0.16
5,000	0.25	1.29	0.5	0.2
6,000	0.29	1.25	0.71	0.24
7,000	0.32	1.2	0.84	0.27
8,000	0.36	1.16	0.92	0.31
9,000	0.4	1.12	0.96	0.34

	Biomass metrics		Harvest metrics	
TAC (metric tonnes)	Prob (below 0.25 SB_0 in 2014) P(SB2014 < 0.25 SB0)	Median ratio of forecast biomass to 0.25 SB_0 Med (SB2014 / 0.25 SB0)	Prob (removal rate > target HR) P(U'2014 > 20%)	Median removal rate Med (U'2014)
Strait of Georgia				
0	0	3.5	0	0
10,000	0	3.31	0	0.08
15,000	0.001	3.22	0.03	0.12
20,000	0.001	3.13	0.19	0.15
25,000	0.002	3.04	0.42	0.19
26,500	0.002	3.01	0.5	0.2
30,000	0.003	2.95	0.66	0.22
35,000	0.005	2.85	0.82	0.26
40,000	0.008	2.76	0.91	0.29
WCVI				
0	0.11	1.55	0	0
2,000	0.16	1.46	0.01	0.09
3,000	0.19	1.41	0.11	0.13
4,000	0.22	1.37	0.32	0.17
4,700	0.25	1.33	0.51	0.2
5,000	0.25	1.32	0.57	0.21
6,000	0.29	1.27	0.75	0.25
7,000	0.32	1.23	0.87	0.29
8,000	0.36	1.19	0.93	0.32

Minor Stock Areas	**Harvest Metrics**	
TAC (metric tonnes)	Prob (removal rate > target HR) P(U'2014 > 10%)	Median removal rate Med (U'2014)
Area 2W		
0	0	0
200	0.1	0.04
300	0.27	0.07
400	0.43	0.09
450	0.5	0.1
500	0.57	0.11
600	0.68	0.13
700	0.77	0.16
Area 27		
0	0	0
50	0.03	0.05
100	0.47	0.1
105	0.51	0.1
110	0.56	0.11
115	0.6	0.11
200	0.94	0.19

Sources of Uncertainties

Recruitment and natural mortality are considered to be the most important processes determining the productivity of BC Pacific Herring stocks. Factors driving age-3 recruitment to the spawning biomass, forecasted by the assessment model, are not fully understood. Median (model) estimates of instantaneous natural mortality appear to be decreasing in all of the major and minor stock areas, except Area 2W. The reasons for these changes are not clear at present, but are under investigation as natural mortality is an important parameter in the stock assessment model. Long term declines in body size (weight at age) have been observed for all BC herring stocks, from the early 1980s-2010 with a leveling off at the low end of the range in most recent year(s) however factors causing these changes are poorly understood.

Uncertainty in the estimated parameters and quantities is explicitly addressed using a Bayesian approach. However, modelled results reflect only the structural assumptions specified in the model and weights assigned to the various data components, representing a minimum estimate of uncertainty. Results from sensitivity runs do not differ greatly from the base runs. Alternative model and stock structure assumptions, including alternative forecasting methodologies, would result in greater levels of uncertainty.

Ecosystem Considerations

Pacific Herring play a key role in marine ecosystems and are a food source for a variety of piscivorous species including Pacific Salmon (Coho – *Oncorhynchus kisutch*, and Chinook, *O. tshawytscha*), Pacific Hake (*Merluccius productus*), Halibut (*Hippoglossus stenolepis*), Arrowtooth Flounder (*Atheresthes stomias*), and Dogfish Shark (*Squalus acanthias*) (Schweigert et al. 2010). Herring are also believed to be important in the diet of marine mammal predators such as Steller (*Eumetopias jubatus*) and California (*Zalophus californianus*) Sea Lions, Harbour Seals (*Phoca vitulina*), Northern Fur (*Callorhinus ursinus*) Seals, Harbour Porpoises (*Phocoena phocoena*), Pacific White-sided Dolphin (*Lagenorhynchus obliquidens*), Humpback Whales (*Megaptera novaeangliae*), and Grey Whales (*Eschrichtius robustus*). During the time period captured in the Pacific Herring assessment (1951-2013), population sizes of Seals, Sea Lions and Baleen Whales, which forage on herring, have increased (DFO 2003; DFO 2010; Carretta et al. 2011; Crawford and Irvine 2011).

Research continues to develop a fuller understanding of ecosystem processes and the role that herring play in maintaining ecosystem integrity and function. Little information is available to develop ecosystem-based conservation limits for herring at present.

CONCLUSIONS AND ADVICE

Previous recruitment forecasting approaches, which used trawl survey data for two stocks (SOG, WCVI) and categorized model-reconstructed recruits (poor/average/good) for all stocks, are not scientifically defensible and do not capture the uncertainty in recruitment forecasts and subsequent risks to BC Pacific Herring stocks. Consequently, it is recommended that the assessment model be used to estimate the probability of breaching thresholds or achieving desirable outcomes for BC Pacific Herring stocks and fisheries.

The Pacific Herring stock assessment depicts five major and two minor stocks with varying levels of productivity that have experienced heavy commercial fishing in the past (pre-1972). In the 2012/13 fishing season, commercial roe fishery opportunities were provided and pursued in the Prince Rupert District and Strait of Georgia, and commercial spawn-on-kelp opportunities were provided and pursued in Area 2W, Area 27 and PRD.

Advice for each Pacific Herring stock is presented in probabilistic decision tables showing predicted status in 2014 given a range of constant catches relative to harvest and spawning biomass metrics relating directly to the existing herring HCR. The assessment results and advice are summarized by management area. The tables assume the assessment model is valid.

Recommendations for future work include evaluating current and proposed alternative Pacific Herring management approaches, including the use of alternative reference levels, via simulation testing. Additional recommendations for future work include evaluating the drivers of recruitment forecasts produced by the assessment model, incorporating sources of fishing mortality not currently captured (e.g., spawn-on-kelp), and the development of biologically-based limit reference points.

SOURCES OF INFORMATION

This Science Advisory Report is from the Regional Peer Review meeting on 'Stock Assessment and Management Advice for BC Pacific Herring: 2013 Status and 2014 Forecast', held on September 4-6, 2013. Additional publications from this process will be posted the on Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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